



Fremtidens vindmøllevinger -når vind globalt leverer over 10 % af vores el

Rasmussen, Flemming

Publication date:
2013

[Link back to DTU Orbit](#)

Citation (APA):

Rasmussen, F. (Author). (2013). Fremtidens vindmøllevinger -når vind globalt leverer over 10 % af vores el. Sound/Visual production (digital)
http://www.dkvind.dk/html/arrangementer/tidligere/021113_vindtraef/program.htm

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Fremtidens vindmøllevinger

-når vind globalt leverer over 10 % af vores el

Flemming Rasmussen

flra@dtu.dk

Sektionen for Aeroelastisk Design
Denmarks Tekniske Universitet
DTU Wind Energy – Risø Campus

Indhold

- Global status for vindkraft
- Status for teknologien og tendenser
- De næste skridt mod fremtidens vindmøllevinger (10 MW Ref. Mølle)
- Fremtidens vindmøllevinger

Antagelse:

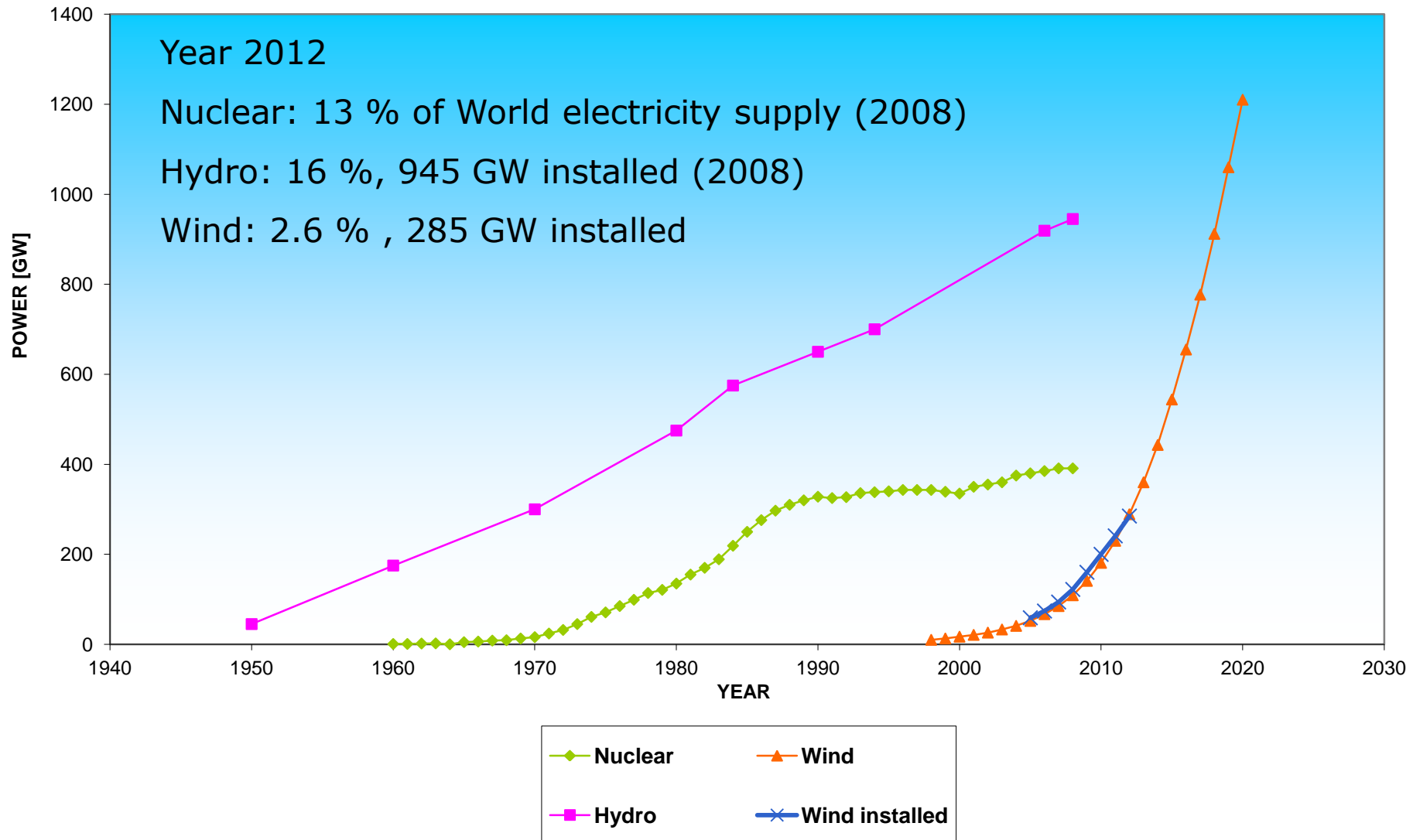
- Vindenergi ændrer rolle til at blive rygraden i en sikker global energiforsyning, eller Vindenergi som "base load".

Prøvestationen for vindmøller, Risø 1979



Accumulated power in the world

10 % Wind energy-scenario (1998)



Vindenergi som "base load"

Verdens elforbrug

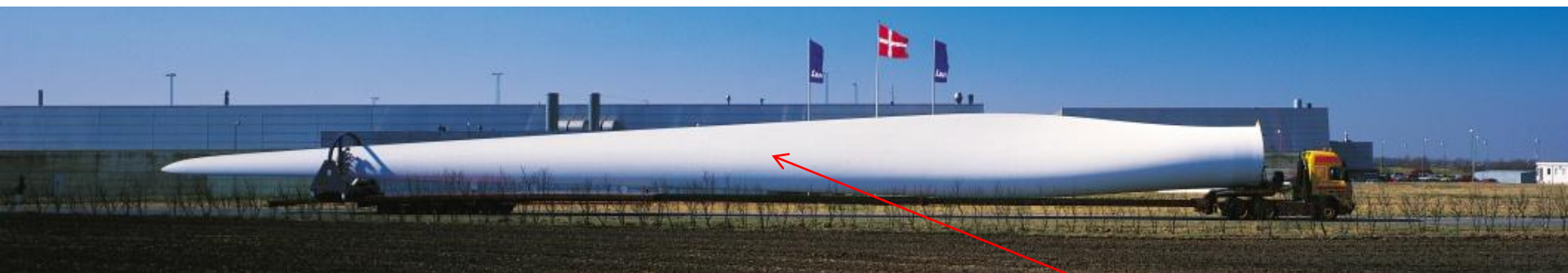


Integration er udfordringen
- Vandkraft
- "pumped storage"
en del af løsningen

Eksempel Norge:
30 GW vandkraft
2 GW pumpekraftværker
ca. 15 GW udbygningspotentiale for begge

Globalt:
Vandkraft leverer 16 % med en kapacitetsfaktor på 1/3
Kunne levere 50 %, "hvis der var vand nok"
Samtænkning vand/vind gør det realistisk

Opskalering



Opskalering med x 100 på 30 år

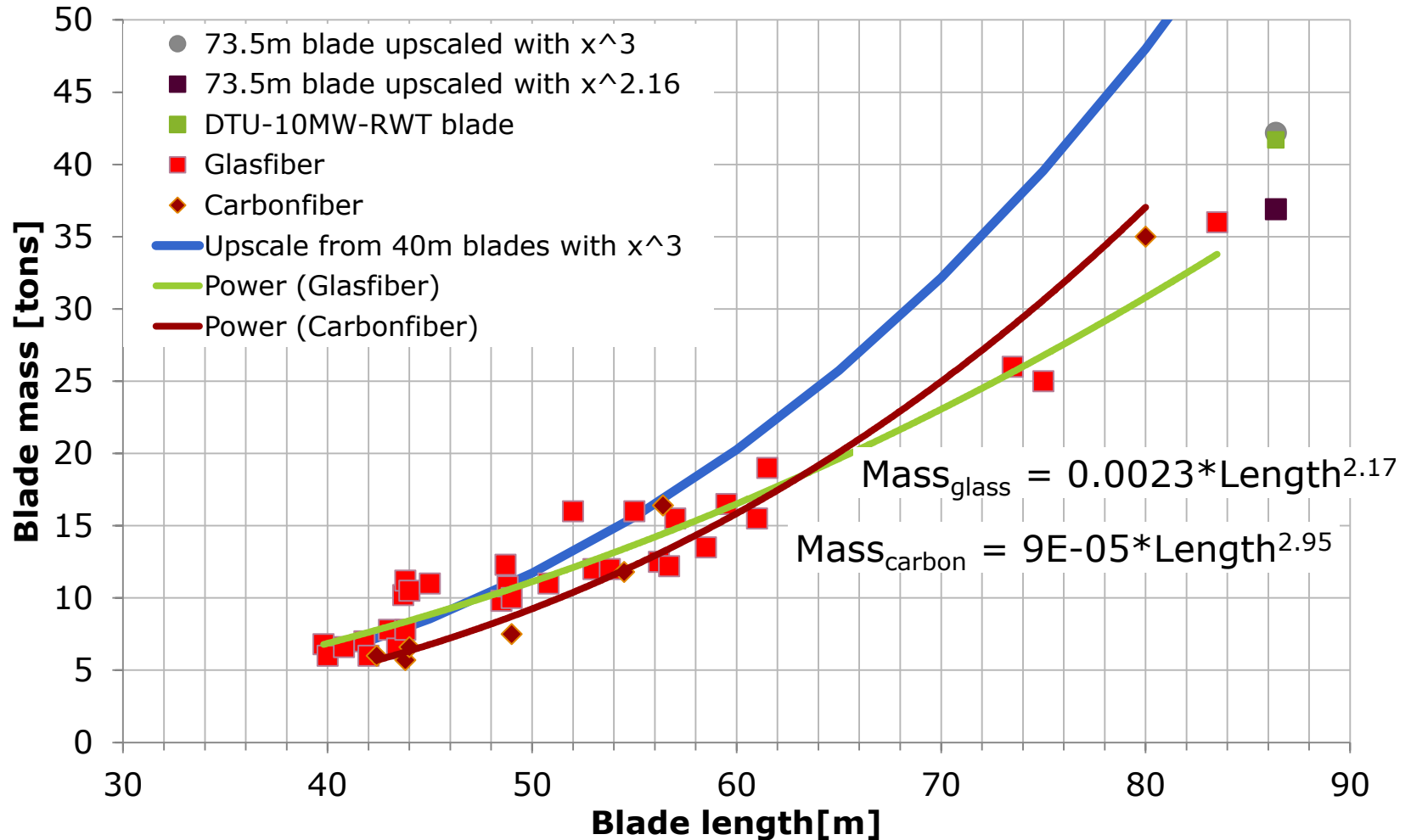
Opskalering, teori: "Square-cube law"

- Effekten stiger med kvadratet på vingelængden
- Massen stiger med tredje potens

Bladmasse stiger kun tæt på diameteren i anden potens (eksponent 2.1-2.3) på grund af optimerede og tykke profiler og optimeret strukturelt design



Aktuel bladmasse og opskaleret til 10 MW



En materiale optimeret maskine, 6 MW



DTU Wind Energy, Technical University of Denmark

10 m/s:

- 200 tons/sek.: Luftmasse gennem rotorarealet.
- Behandler luftmasse svarende til møllens totalvægt på 5 sekunder.
- Yderste $\frac{1}{4}$ af vingerne overstryger enormt areal med meget lidt materiale
- Aksialtryk og drejningsmoment.

Typisk vindmølle 2012



Wind turbine 2012

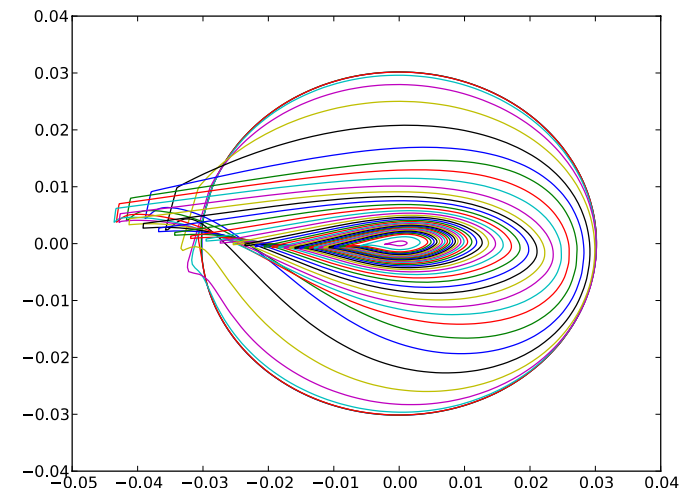
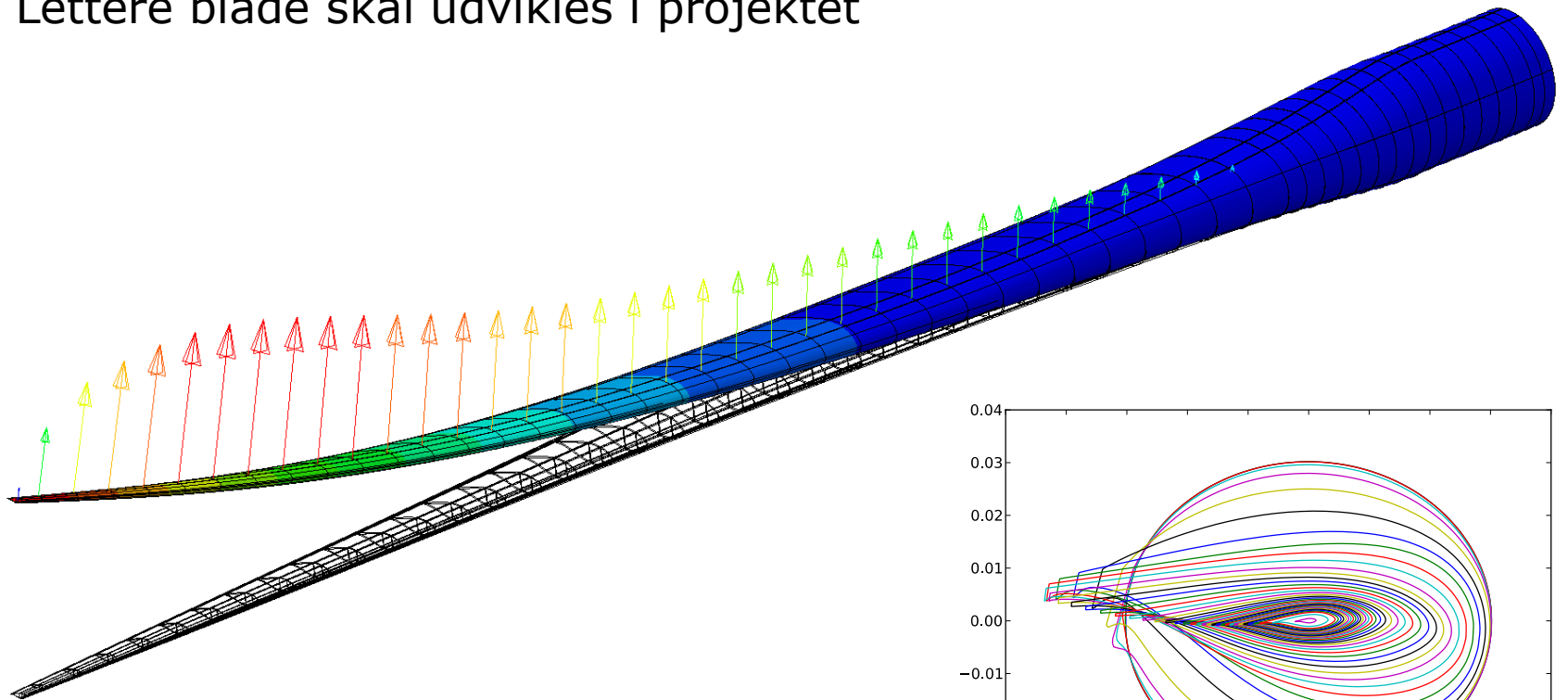
Resultat af 30 års optimering.
Ved direkte opskalering fra
55kw ville 6 MW møllen være
10 gange tungere.

Karakteristika:

- ☐ Negativ koning
- ☐ Høj tilt
- ☐ Fra at designe for stivhed til
at designe for styrke
- ☐ Mere optimeret
- ☐ Mere fleksibel
- ☐ Slanke vinger med tykke
profiler

Light rotor projekt med Vestas Blad til 10 MW vindmølle

- Det er et reference blad som er designet med eksisterende teknologi til brug også i INWIND.EU projektet
- Lettere blade skal udvikles i projektet



DTU 10 MW Reference rotor

Nominal power	10.0 MW
Rotor configuration	Upwind, 3 blades
Control	Variable speed, collective pitch
Rotor diameter	178.3 m
Hub height	119.0 m
Rated tip speed	90 m/s
Blade pre-bend	3.3 m
Tower mass	628.4 tons
Nacelle mass	446.0 tons
Rotor mass	230.7 tons
Blade mass	41.7 tons



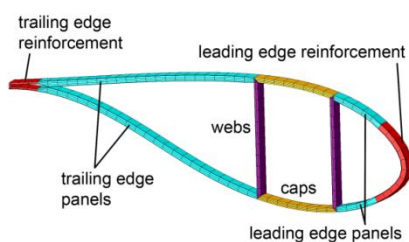
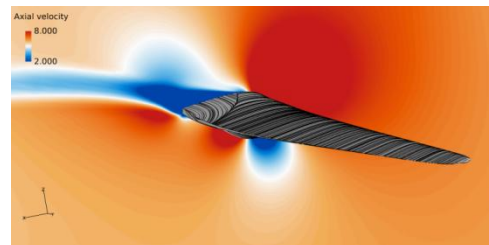
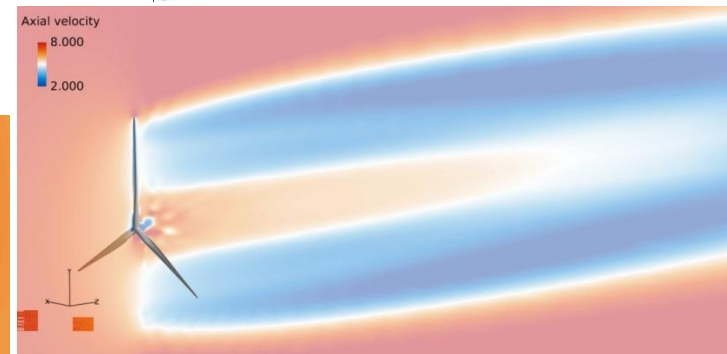
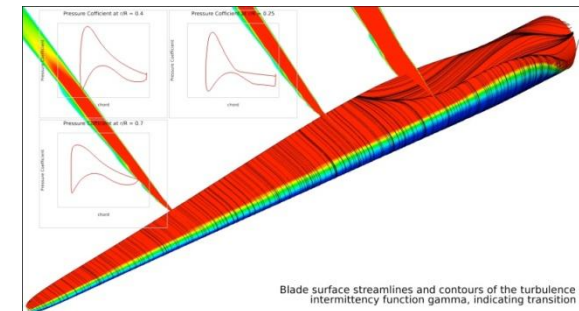
Light Rotor 10 MW Reference Rotor

• Specs

- IEC IA
- Rated power=10 MW
- Rotor
 - Radius=89.17m
 - Airfoils: FFA-W3-xxx
 - Max tip speed=90m/s
 - Optimal TSR=7.5
 - Control: PRVS
 - Upstream cone, tilt and prebend
- Specific power=407W/m²

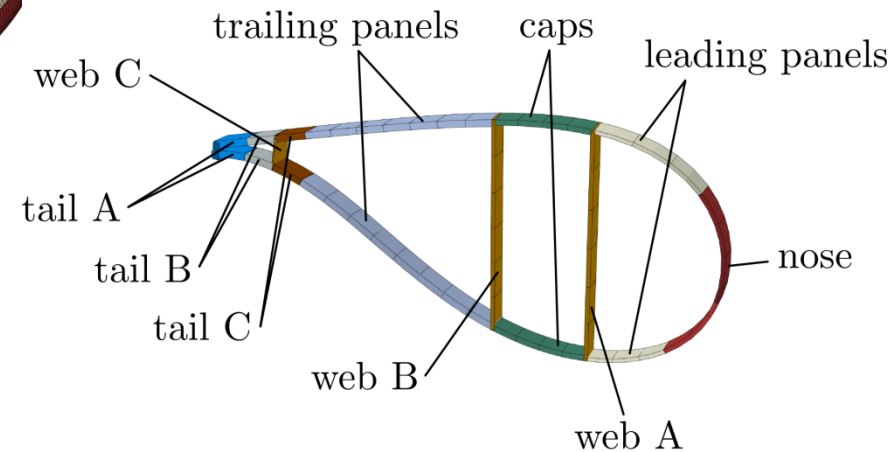
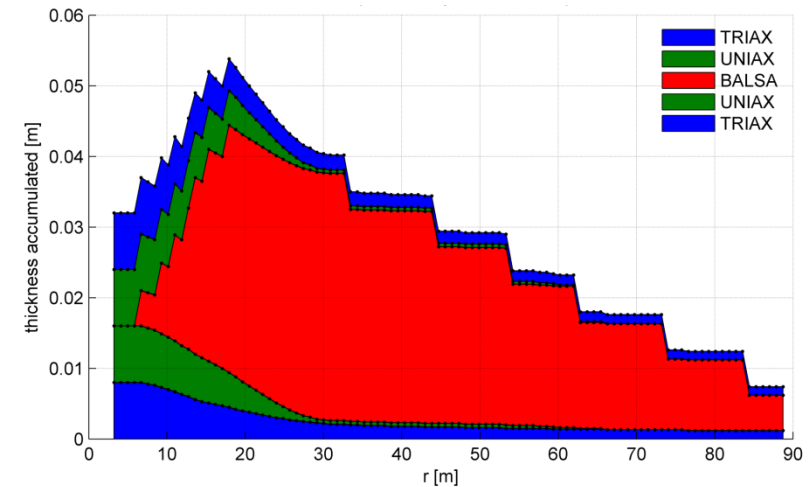
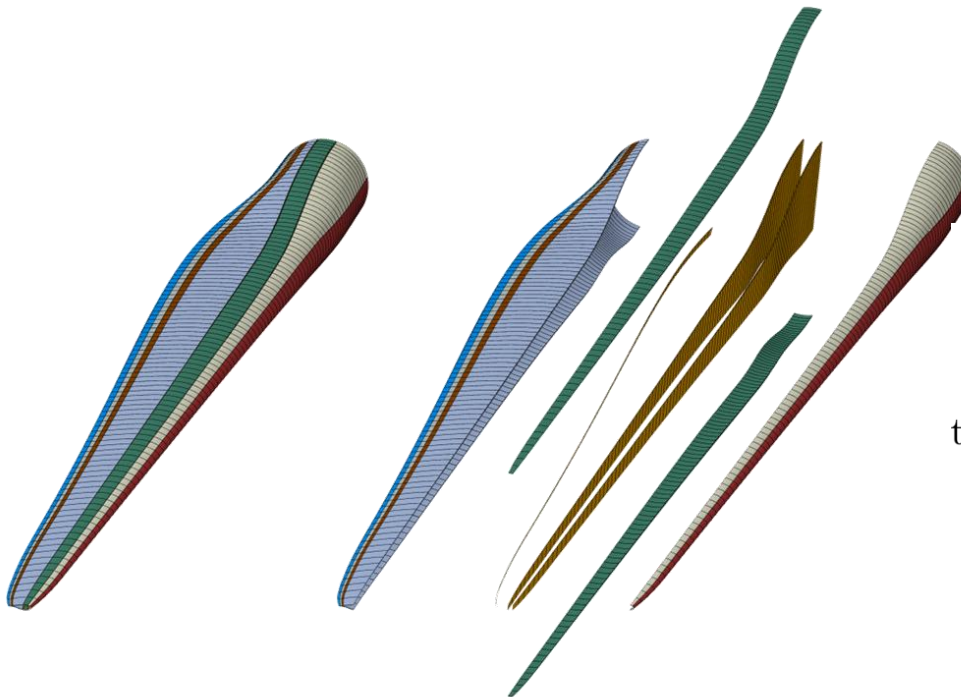
• Investigations

- Full aeroelastic load calculations including control
- Aeroelastic stability computations
- Full 3D CFD rotor computations
- Full FEM model of blade

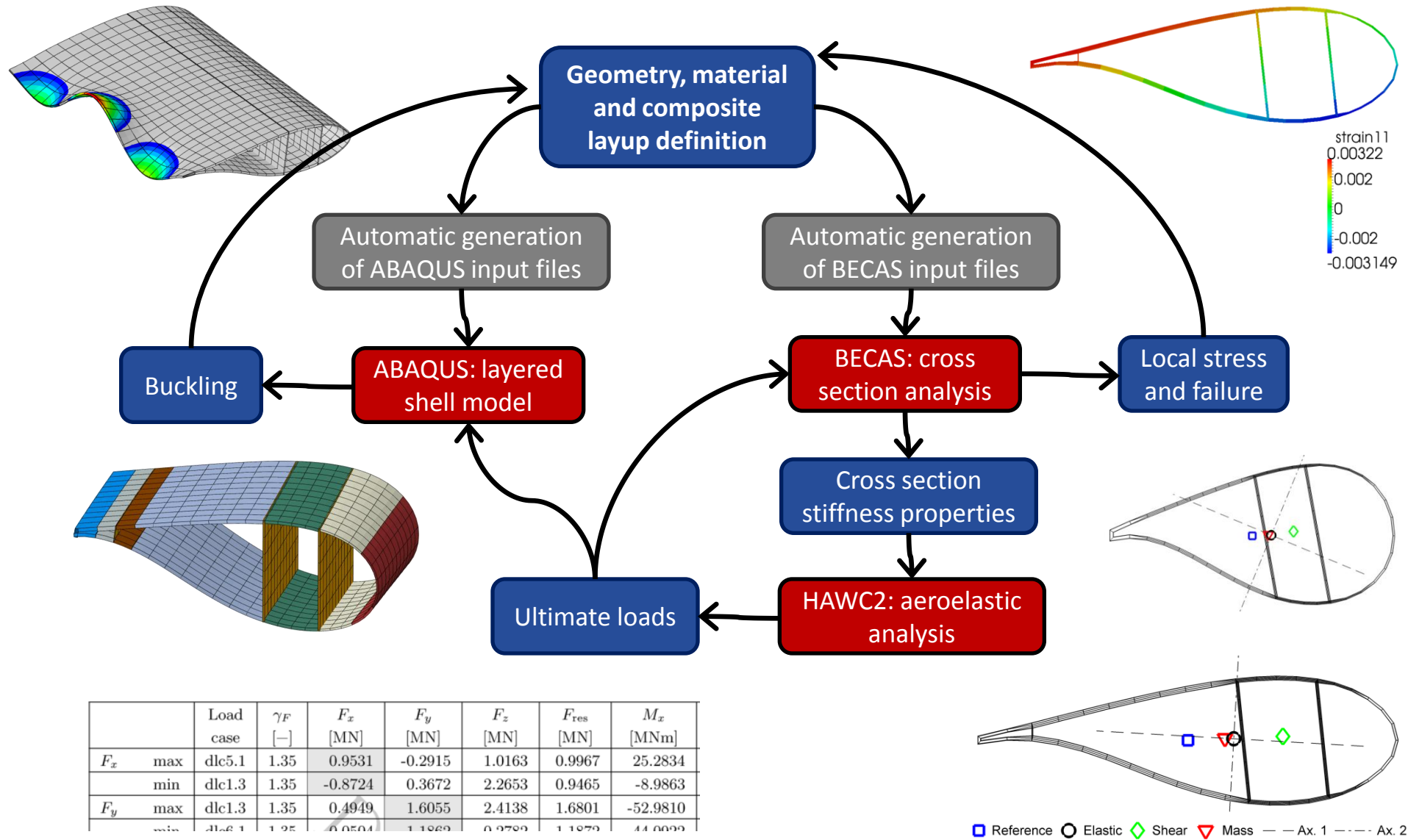


The DTU 10 MW Reference Wind Turbine Structural Design

- Layup definition of the blade in 100 regions radially and 10 regions circumferentially.
- Geometry and layup is generated in a finite element shell model.



The DTU 10 MW Reference Wind Turbine Structural Design: Design loop



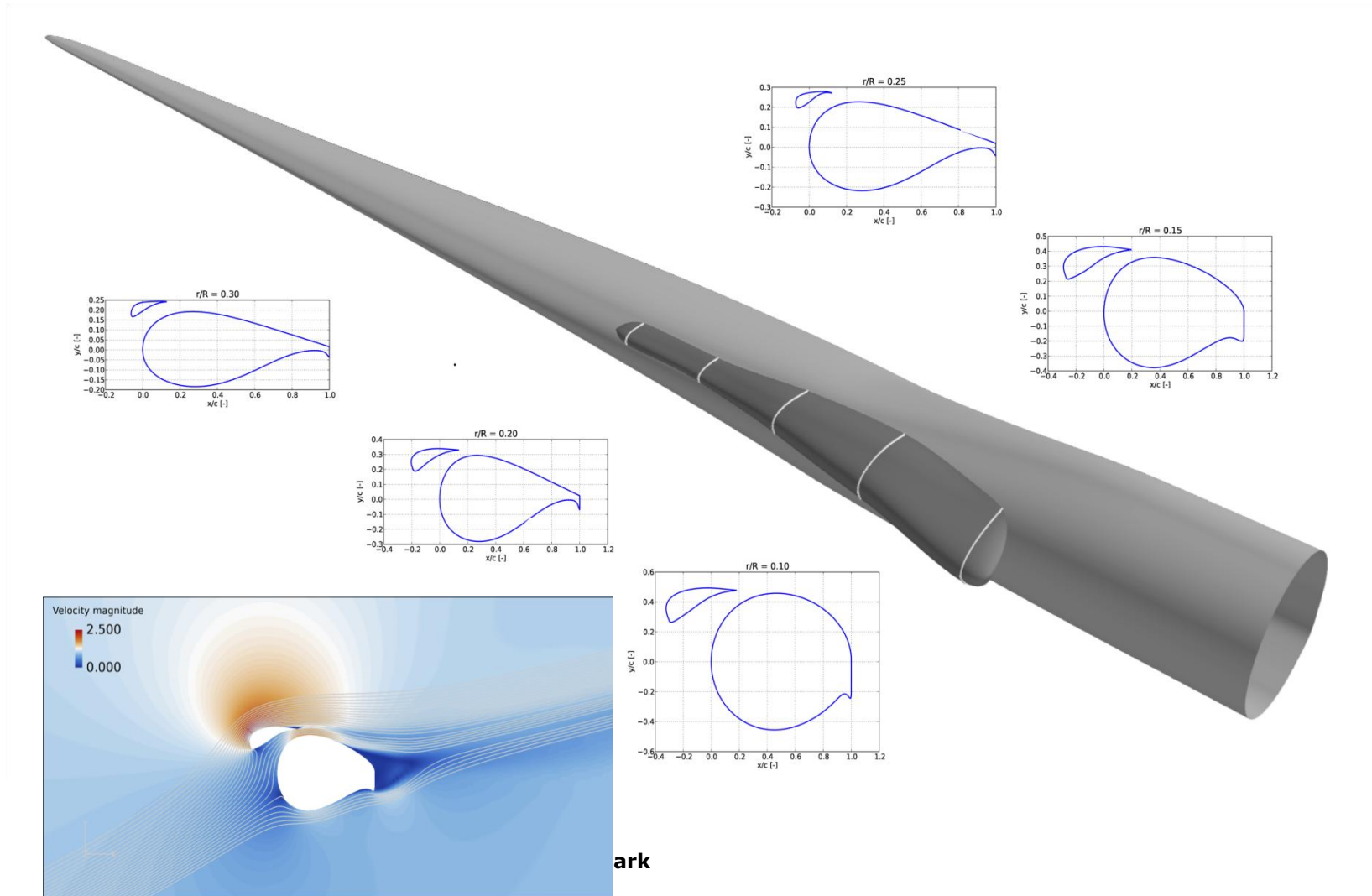
Næste skridt mod fremtidens vindmøllevinger: Videreudvikling af DTU 10 MW Ref.-roteren



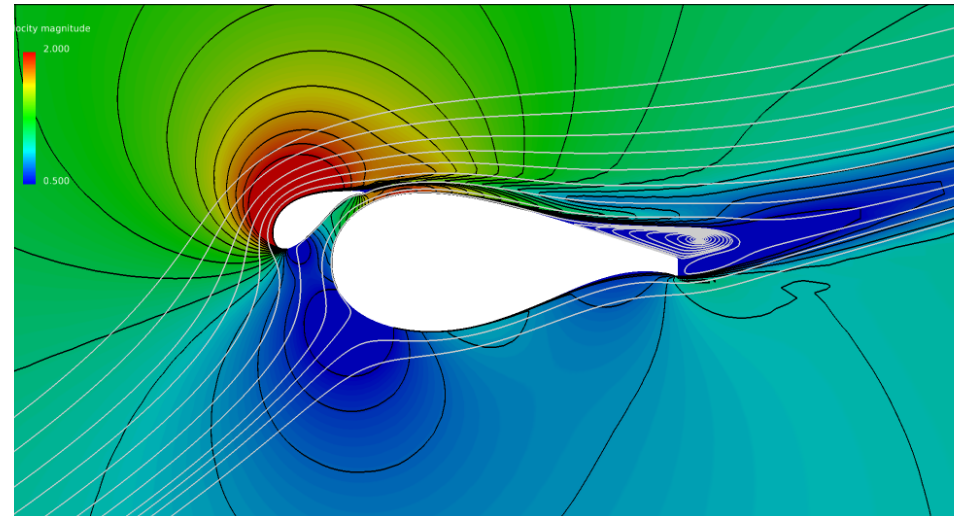
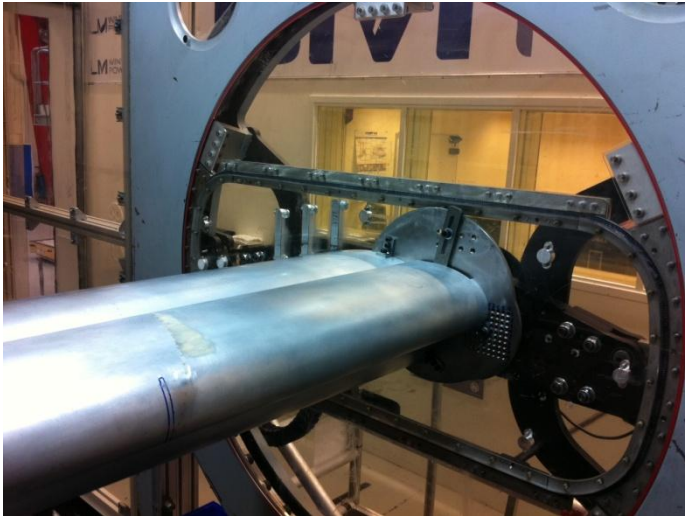
Parameterstudier:

- Passivt indbygget kontrol, herunder flow-kontrol
 - Gurney flaps
 - Vortex generatorer
 - Slats
 - Tipudformning
 - Flap/twist kobling
 - Flap/profilkrumning kobling
- Aktiv kontrol
 - Kombineret pitch og aktiv bagkant-flap kontrol
- Øget tiphastighed
- Længere vinger
- Antal blade
 - Trebladet/tobladet

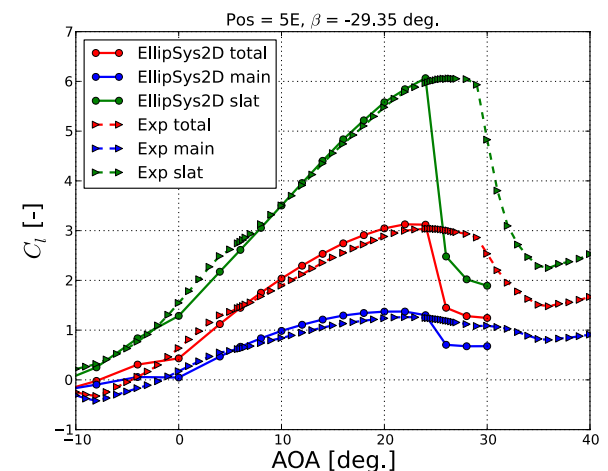
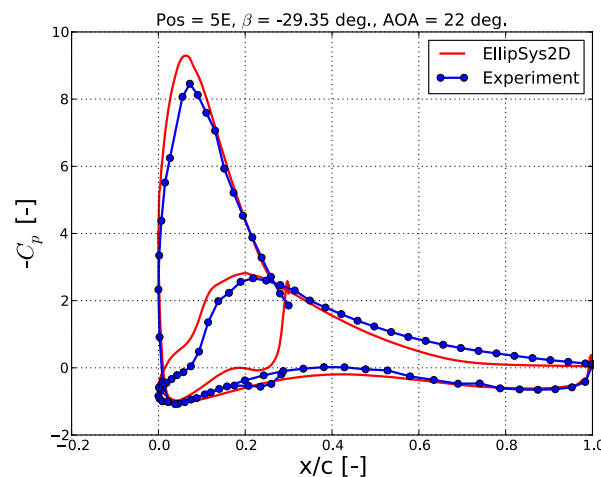
LightRotor 10 MW RWT blade with multi-element airfoils



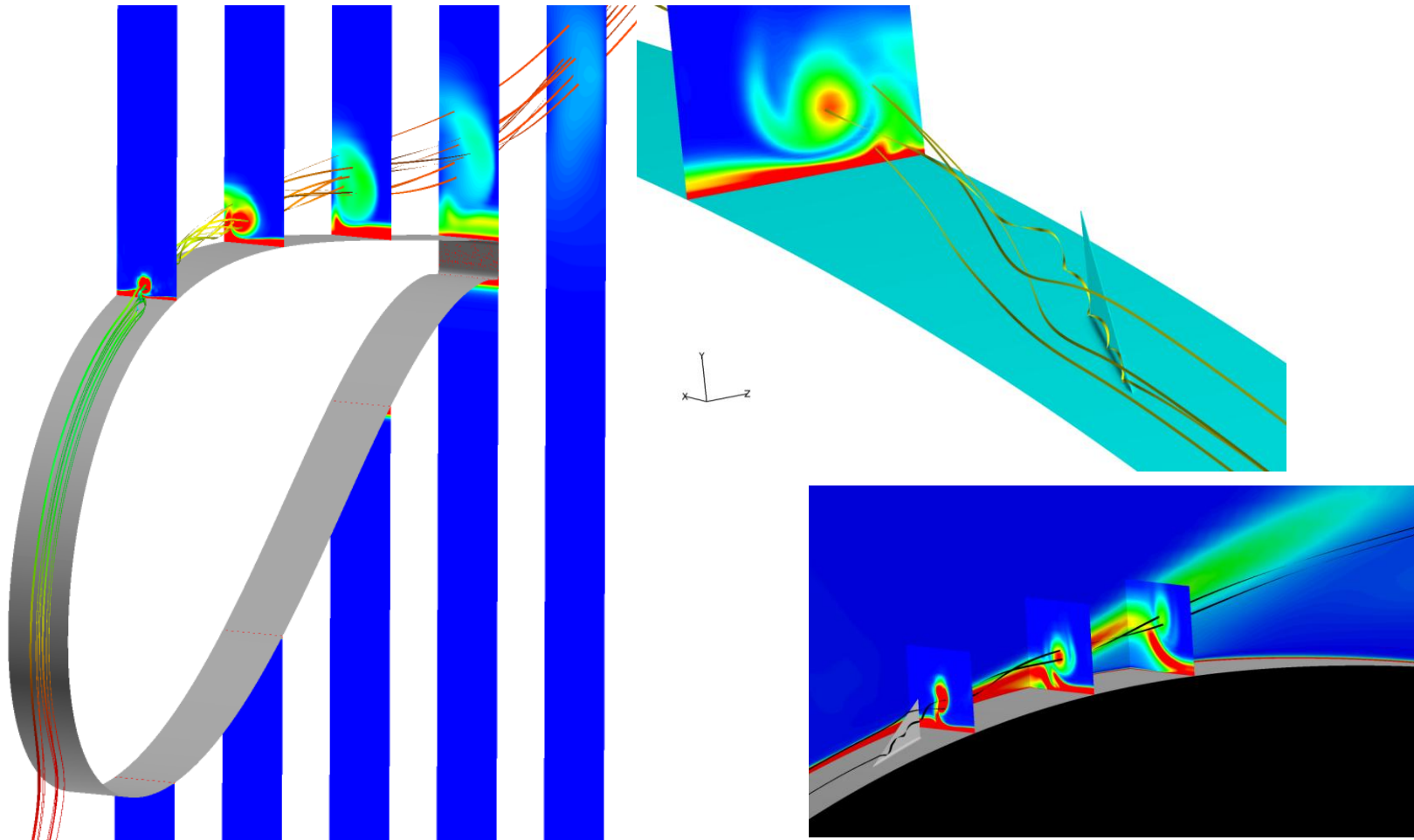
Thick flat back airfoil with slat



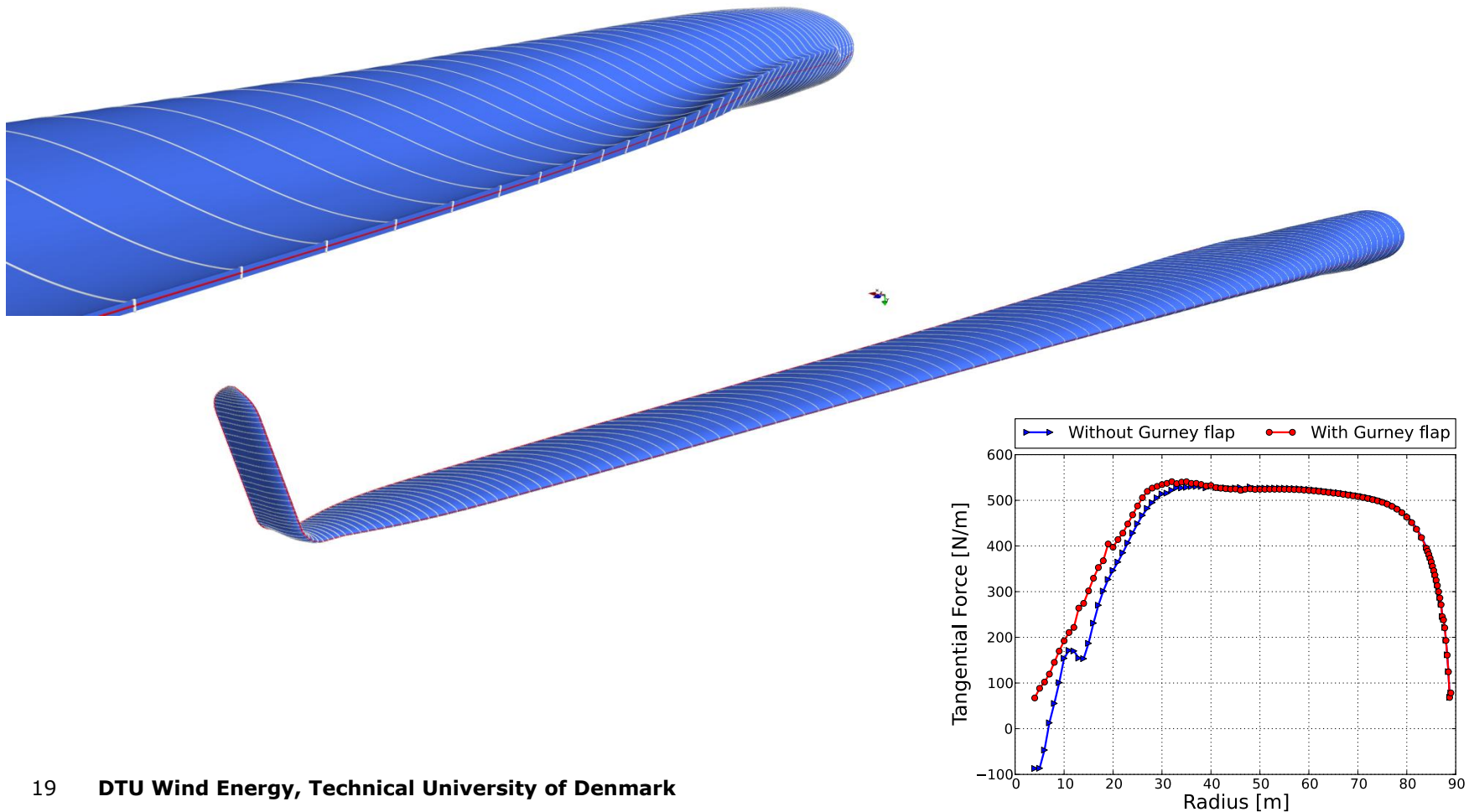
- A multi-element airfoil was designed and tested
- The slat was designed using an optimization tool coupled with EllipSys2D.
- 2D CFD succeeded to a large extent in predicting the correct characteristics.



Flow control med vortex generatorer

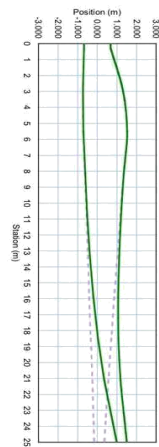
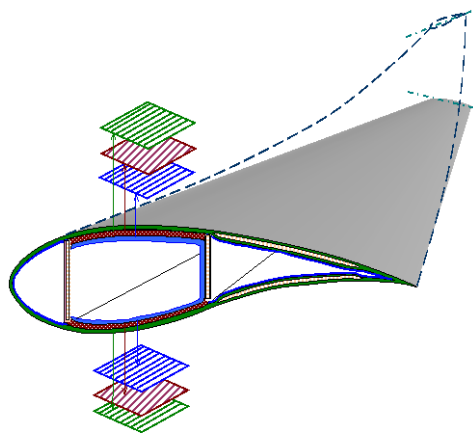


LightRotor 10 MW RWT blade with winglet and flat-back airfoils at root with Gurney flap

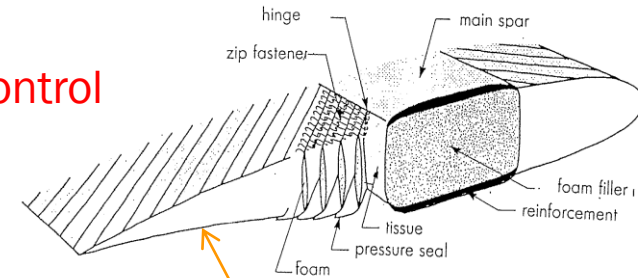


Flap-torsion coupled blade

Combined passive built-in coupling and multi-variable control
- an optimum design



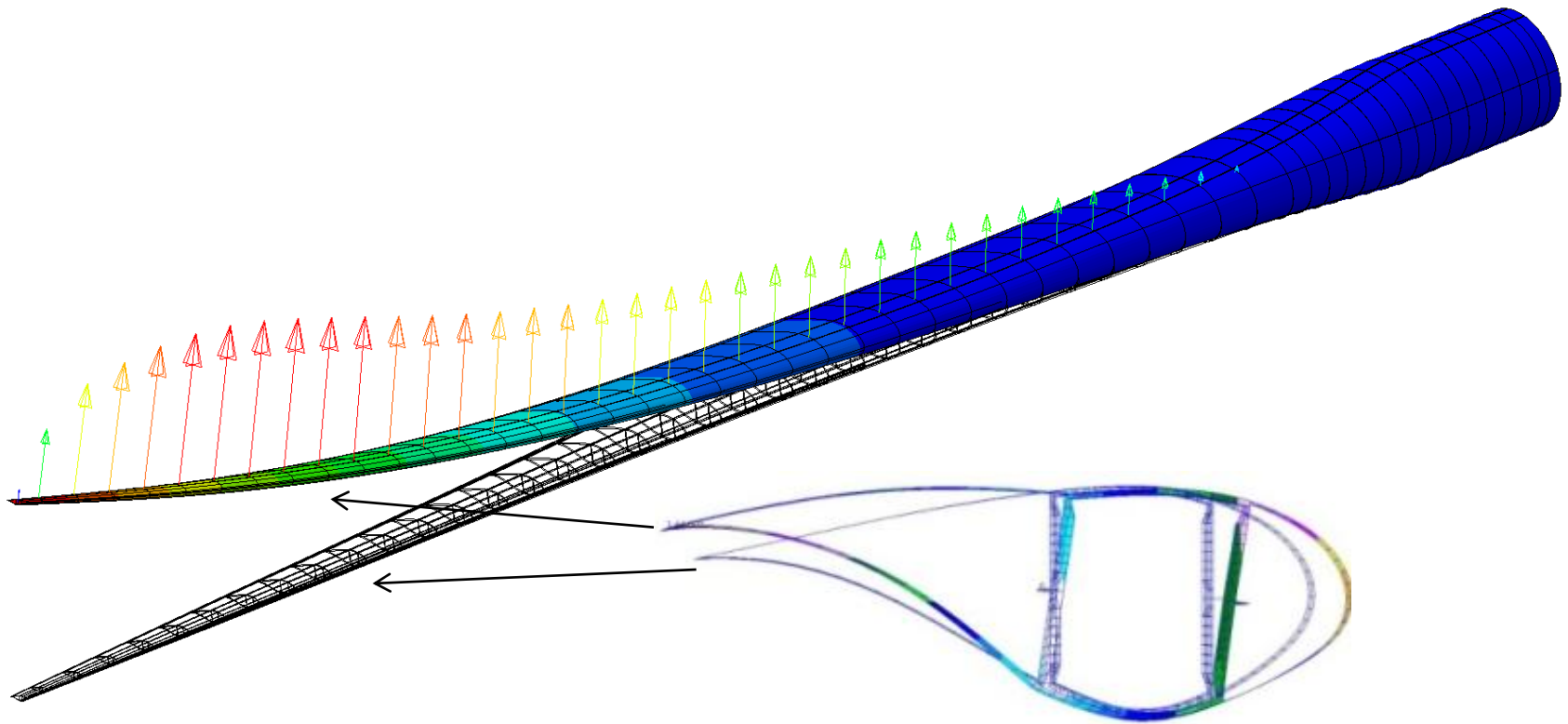
A Twist-flap Coupled Blade Design to Alleviate Fatigue Loads (on the left with material coupling and on the right with a curved blade)



Feather

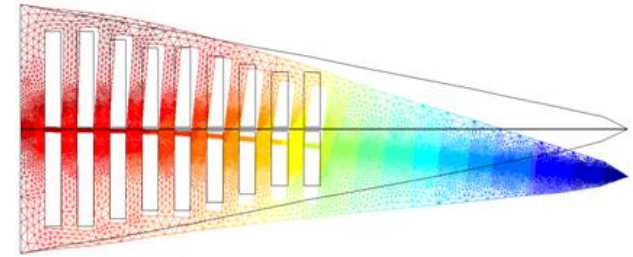


Possible flap-camper coupling?

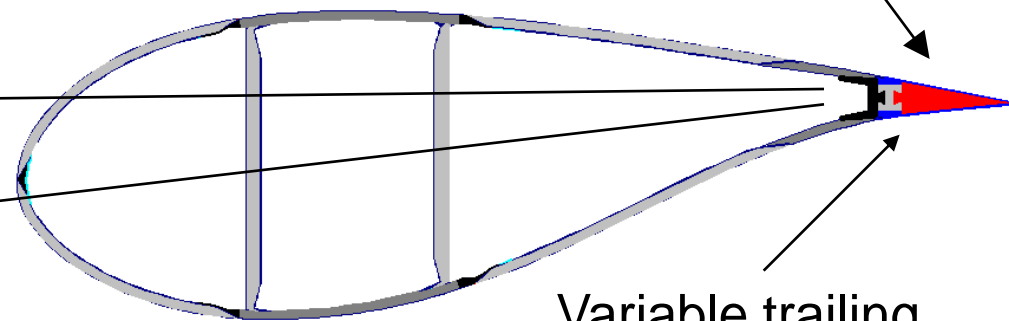
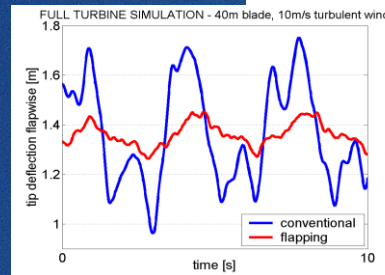


Blade pitch and trailing edge control

Elastomeric controllable flap
activated by pressure in voids

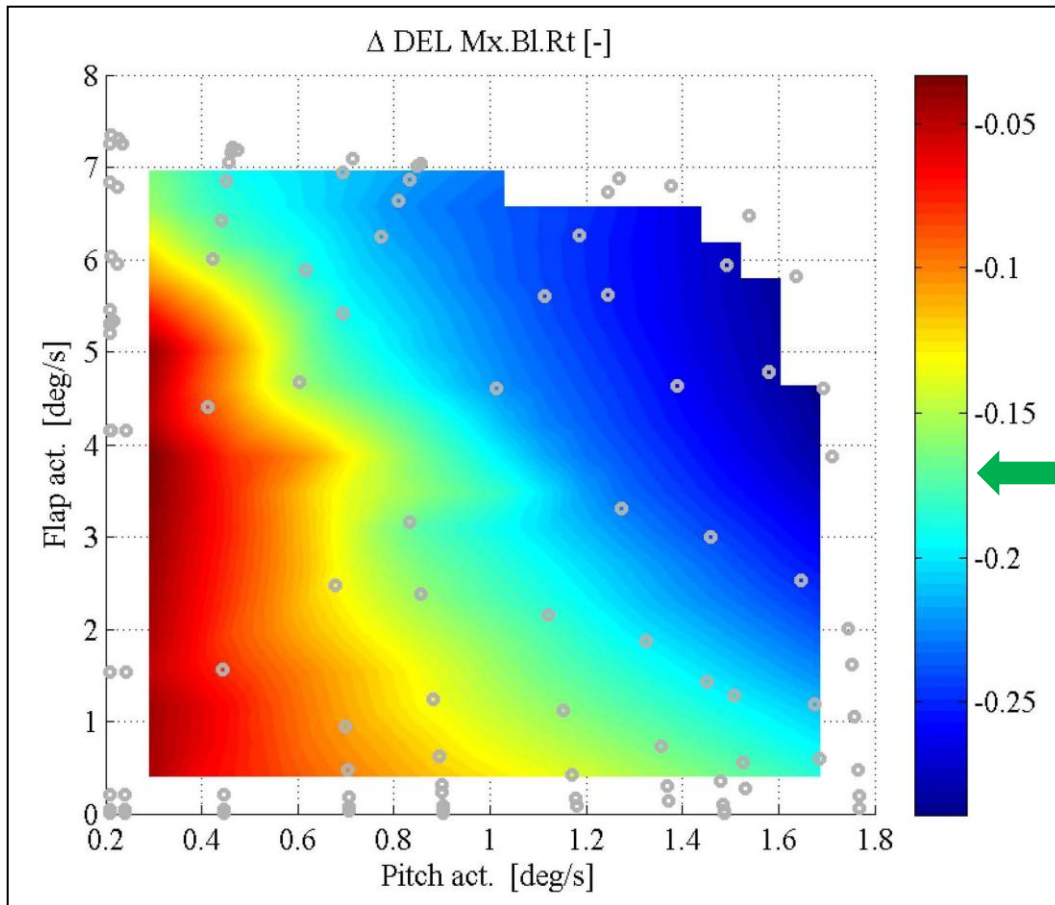


20-40% reduction in blade-
and tower fatigue loads



Variable trailing
edge flap

KOMBINERET PITCH OG FLAPKONTROL BASERET PÅ MÅLING AF FLAPMOMENT I RODEN



CONTROL OBJECTIVE:
Reduce the pitch activity and alleviate the loads using the same sensors as for the pitch system

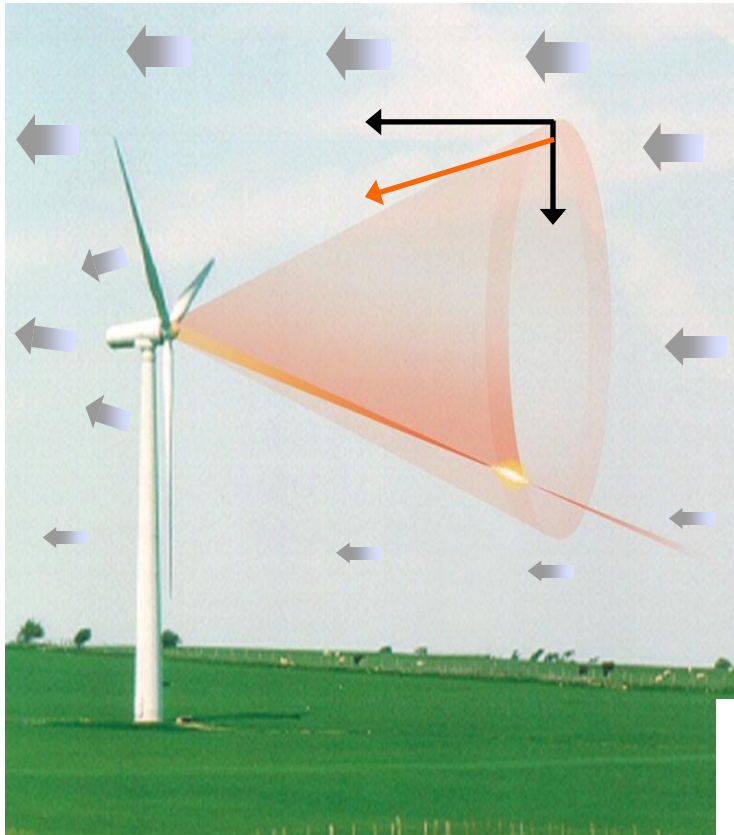
Fatigue Damage
 Equivalent Loads (DEL)

% alleviation at root
 flapwise bending

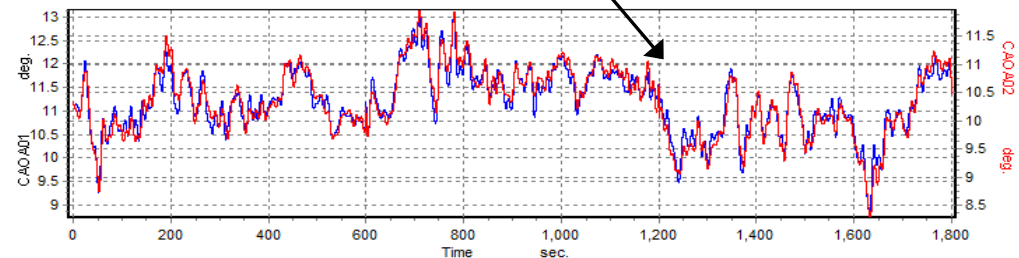
IEC class IA
 18m/s

Measuring inflow for pitch or flap control

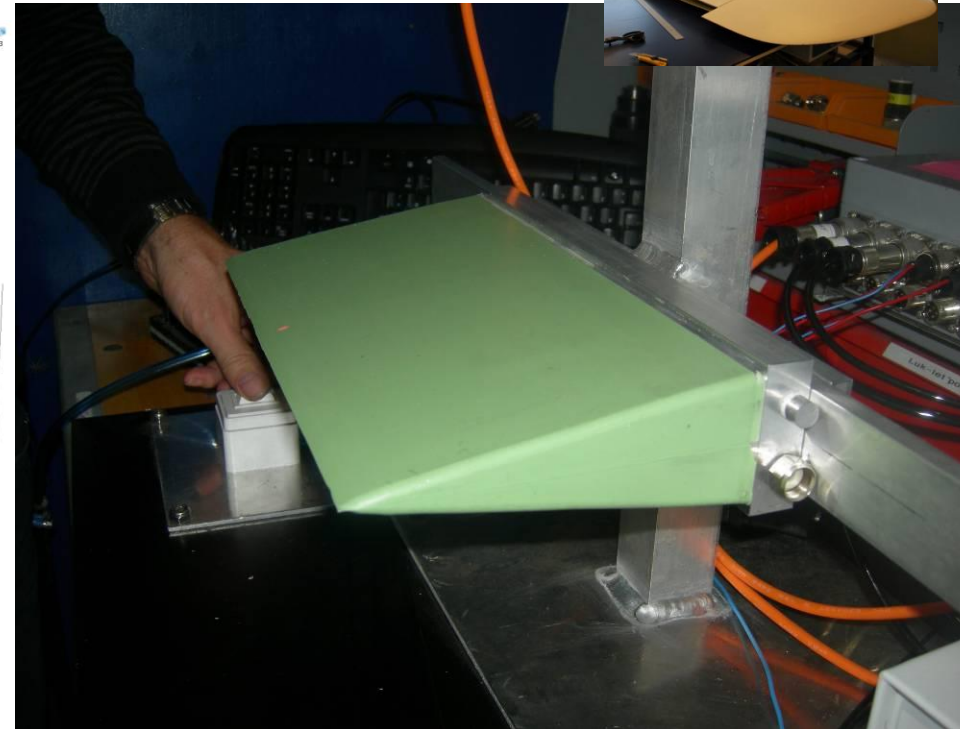
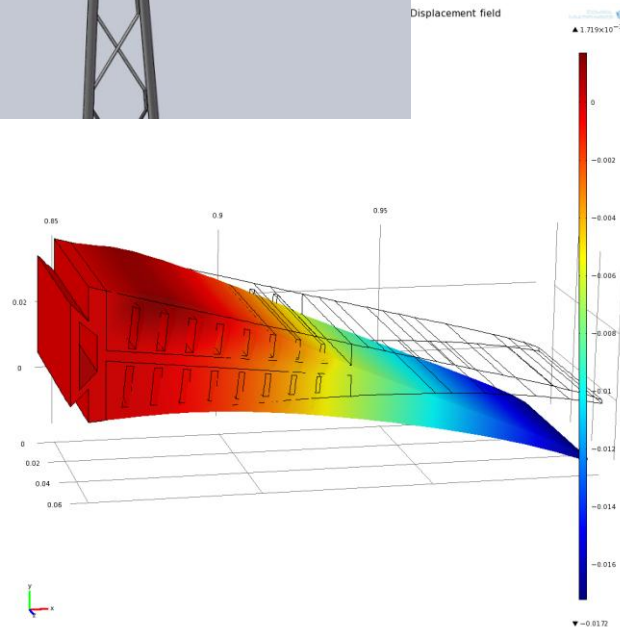
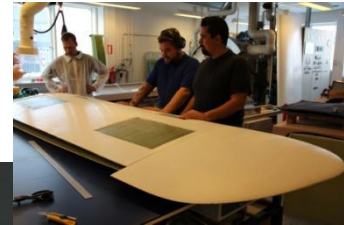
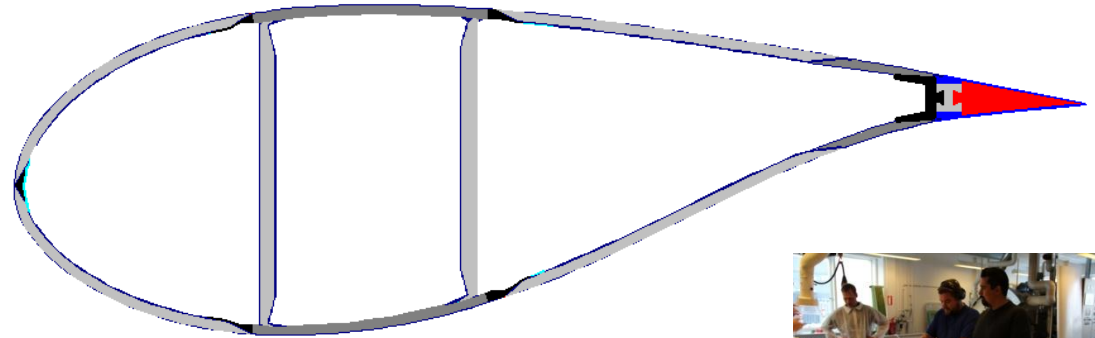
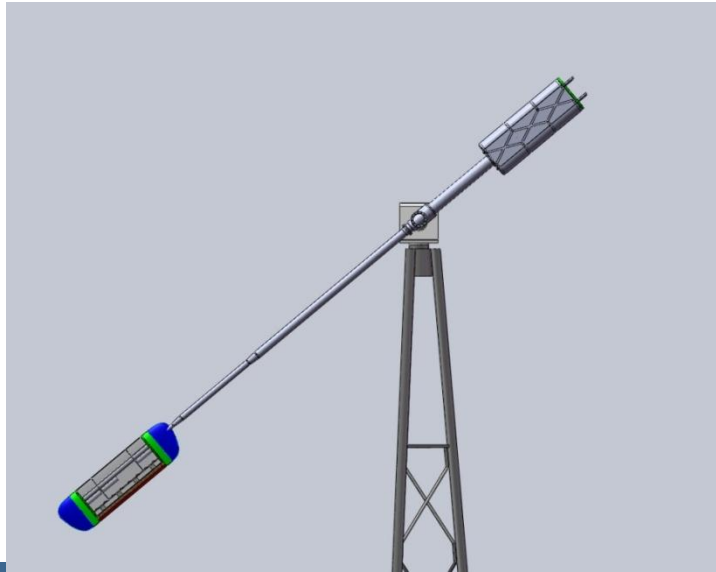
Lidar technology



Inflow measured with
four five hole pitot
tubes

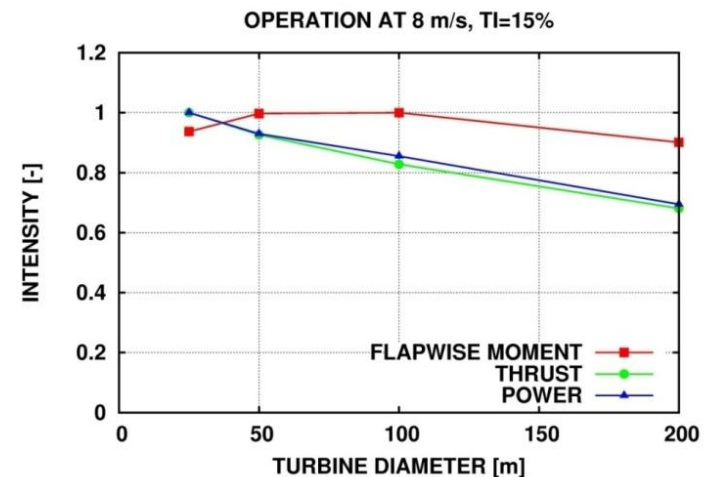


Rotating test rig and rubber trailing edge flap



Forhold ved opskalering

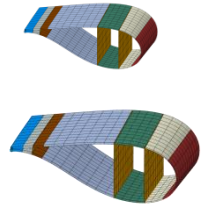
- Stigende Reynoldstal en fordel op til 10 Mio. (ca. 10 MW). Derefter en ulempe?
- Øget tipastighed (Mach nr.) en ulempe efter 90 m/s
- Turbulens: Filtrering fra roterende sampling giver relativt mindre laster



Antal blade: 2-bladet/3-bladet

Den 2-bladede har:

- 50% større korde
- 4% mindre virkningsgrad
- 15 % større turbulenslastinput (fordi $2p < 3p$)
- Ca. 2/3 rotorvægt

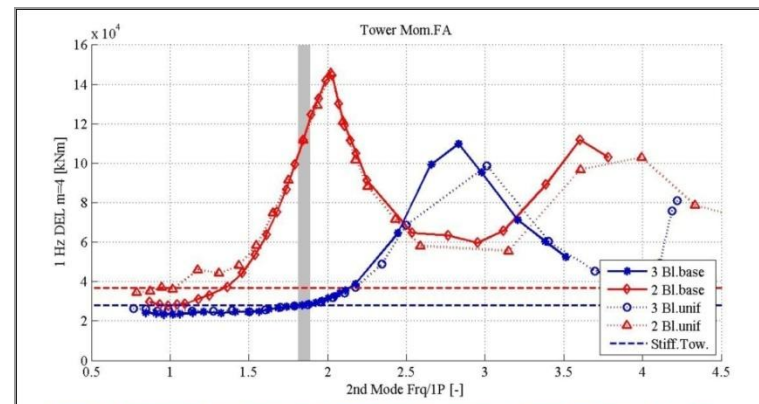


Med vippenav:

- Ca. 50% rotorvægt
- Bladlast \sim bladlast for 3-bladet
- Mulighed for større diameter



- Tårnegenfrekvens skal være lavere (ned mod 1p)



Perspektiver

- Er lavt belastede rotor (som kører lavere belastet end det optimale) og derved giver mindre wakeeffekt i parker kost-effektive?
- Kan man forestille sig, at passiv og aktiv kontrol ud langs vingerne kan regulere effekten så hurtigt, at man igen kan køre med fast omdrejningstal?
- Opskaleringen har igen taget fart, og 10 MW er realistisk. Vil den fortsætte til 20 MW?
- **Fremtidens vinger bliver længere – både relativt og absolut.**